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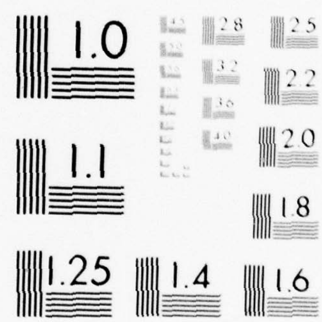

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Wright-Patterson Air Force Base, Ohio

VALIDATION OF THE DETROIT DIESEL
ALLISON LOGISTIC SUPPORT COST
MODEL (PROGRAM OS590)

Howard E. Creek, Captain, USAF
C. N. Harlambakis, Jr., Captain, USAF

LSSR 20-79A

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The Department of Defense (DoD) is genuinely concerned about Operation and Support Costs (O&S) during the early stages of the acquisition process. An area of particular interest to the Air Force Aero Propulsion Laboratory (AFAPL) was the validation of Detroit Diesel Allison's O&S cost model, OS590. This study was designed to assist the AFAPL in determining O&S costs for future advanced high technology turbine engines. The results of this research include the following findings: (a) input data for OS590 within the scope of this effort was available from Air Force sources; (b) OS590 produced valid O&S costs; (c) OS590 was sensitive to selected input parameters; and (d) the Directorate of Propulsion YZLR reviewed and agreed that OS590 was complete.

LSSR 20-79A

VALIDATION OF THE DETROIT DIESEL ALLISON LOGISTIC SUPPORT COST MODEL (PROGRAM OS590)

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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June 1979

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This thesis, written by

Captain Howard E. Creek

and

Captain Christopher N. Harlambakis, Jr.

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

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Leslie J. Zambo

COMMITTEE CHAIRMAN

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CHAPTER I

INTRODUCTION

Department of Defense (DoD) Directive 5000.28 states:

> Life cycle cost objectives shall be established for each acquisition and separated into cost elements within the broad categories of development, production, operation, and support. As system definition continues, the cost elements are firmed into cost goals to which the system will be designed and its cost controlled [21:3].

Estimating Life Cycle Cost (LCC) for the acquisition of propulsion systems is a relatively new, complex task (3). Detroit Diesel Allison (DDA) was tasked under USAF contract to develop an Operating and Support (O&S) LCC model to identify ". . . benefits of advanced engines technologies on a weapons system life cycle cost basis [6:1-1]." The result of this contract was the development of Logistic Support Cost Model (Program OS590) (6:1-1). Detroit Diesel Allison stated that "this model is currently the cornerstone of our analysis in evaluating the benefits of new technology concepts [6:1-1]."

Problem Statement

DoD recognizes that cost reduction is of paramount importance and that the investment in developing advanced technology must have a significant payoff (6:1-1). DoD has placed special emphasis on the O&S portion of LCC. The

Deputy Secretary of Defense has expressed concern that

> . . . insufficient attention is being paid to O&S costs. Reduction of these costs through decisions based on realistic cost estimates offers an opportunity for increasing real DoD purchasing power [20:1].

As developmental manager of propulsion technology programs, the Air Force Aero Propulsion Laboratory (AFAPL) has the need to validate the Logistic Support Cost Model (Program OS590)[1] with existing Air Force data in order to produce a creditable LCC estimate for aircraft turbine engines.

Background

Since the AFAPL is the developmental manager of propulsion technology programs, it has the responsibility for estimating the LCC of Air Force turbine engines during the advanced development phase. While estimating LCC, AFAPL has encountered difficulty identifying Air Force Logistics Command (AFLC) data inputs and models/techniques which estimate operation and support costs, and determining which of these models/techniques can be used (3).

LCC has been emphasized as a decision criterion throughout the acquisition process for major systems (21:1-5). To meet this criterion, costs are predicted for the various phases of the system's life. These phases are defined as conceptual, validation, full scale development,

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[1]Hereafter called OS590.

production, operations, and disposition (13:3). AFAPL has used models such as the Acquisition Based on Logistics Effects model (ABLE), the Logistics Support Cost (LSC) model, and the RAND model to assist them in studying front end (conceptual, validation, full scale development, and production phases) costs. However, as pointed out in the report of the 1976 DoD Procurement Management Review of Aircraft Gas Turbine Engine Acquisition and Logistic Support, there has been very little study of O&S costs (17:43). Since the O&S cost can account for 60 to 70 percent of the total costs of systems, accurate modeling of these costs is essential for valid LCC estimation (4:20). DoD has the problem that unless O&S costs are given more consideration, savings generated by low initial procurement costs may soon disappear because of large life cycle support costs. LCC must then be considered early in the system acquisition process to avoid building systems requiring huge expenditures for support cost. In order to do this, accurate estimates of O&S costs are needed early in the development phases of a system. Operating and support cost models could assure these valid estimates (15:19).

To overcome this problem, the AFAPL has sponsored several research projects through the Air Force Institute of Technology to develop or identify models which could be used to better estimate O&S costs (14).

One area in which research was needed was the identification of existing models which could be used by AFAPL to estimate engine O&S cost. As a result, O&S cost models are a concern to AFAPL and are vital to Air Force LCC implementation (3).

Of the numerous models available, the Air Force uses basically three types of models in O&S. These are: (1) cost factor models, which are used to compute estimates of weapon systems O&S cost, (2) accounting models, which compute the O&S portion of LCC as a function of equipment and logistics parameters, and (3) cost estimating relationships, which are equations which reflect O&S costs as a function of design or performance parameters (5:83). OS590 is a cost factor model (3).

Cost factor models estimate O&S costs at the weapon systems level by identifying such cost elements as spares, support equipment, manpower, and maintenance requirements. The ease of using the cost factor model depends heavily on the data base of cost factors that can be updated periodically to reflect the Air Force's most recent O&S cost experience (5:84).

As shown, AFAPL has had difficulty in determining O&S cost estimates. As a result, AFAPL has put emphasis on O&S cost models to assure valid LCC estimates. The next section reviews previous attempts at LCC estimates that have

fallen short of the LCC needs of the AFAPL but provide a stepping stone toward the desired results that the AFAPL requires in determining O&S costs.

Literature Review

There have been many studies utilizing quantitative and qualitative LCC estimates for the acquisition of defense systems; however, a literature search revealed two studies which utilized quantitative models for determining LCC estimates for aircraft propulsion systems. These are the Turbine Engine Life Cycle Cost Model, 1 February 1977[2] and the RAND Corporation's Life Cycle Analysis of Aircraft Turbine Engines, March 1977.

The Joint USAF/Industry Model ". . . has been developed specifically for use during source selection [8:1]." This model is relevant to LCC estimating by facilitating clear communication between the Air Force and the bidders. It also provides cost visibility for all Contractor and specified Government costs (8:1). The Joint USAF and Contractor Committee which developed this model gave the following warning concerning the use of this model.

> Use of this model for any purpose other than source selection is not recommended without a comprehensive reassessment of the model . . . [8:1].

The LCC estimate produced by this model is not an absolute

[2]Also called the Joint USAF/Industry Model.

cost, but rather a comparative cost. The Government will determine which equations from this model will be used during source selection. The Government also requires that the contractor furnish the highest possible level of cost breakdown for the engine, i.e., engine level, engine section level and engine assembly level (8:1). This model falls short in that the Air Force does not maintain all the data used by this model in the detail required by the model (3). The RAND Corporation's model, Life Cycle Analysis of Aircraft Turbine Engines, is also relevant to LCC estimating.

The RAND Study is relevant to OS590 because like OS590 it enables the weapon system planner to acquire early visibility of cost magnitudes, proportions, and trends associated with an engine's life cycle (3). Also, both models use turbine engines as a promising subject for study because: (1) they are extremely important in weapon system applications; (2) they are felt to be the pacing subsystem in aircraft weapon system development; (3) they represent a large inventory and budgetary expense; and (4) they could provide insights, from a subsystem viewpoint across the life cycle spectrum, that may be readily applicable to the weapon system level (14:2-3). In addition, both studies were prompted by the fact that the costs of acquiring and owning turbine engines have escalated steadily over the years (14:v).

The manner in which the RAND model contributes to this analysis of OS590 is not so much in the methodology that was used but more from the lessons learned in analyzing the final results (11). The main difficulty confronting the RAND study was that it required disaggregated, homogeneous, longitudinal data associated with specific engine types (13:1). However, the data that were available were a mass of distinct engine characteristics of many turbine engines gathered together covering only a short period of time. RAND insisted on a data base that spanned a thirty-year period of aircraft turbine engine history; however, they realized in their final results that the maturation process must be more fully understood (14:44).

> It takes a long time for engines to mature (commercial practice indicates five to seven years), and thus average costs over an operational time span are significantly higher than mature-engine steady-state costs [14:44].

The difficulty in acquiring data for the RAND study lies with the variables within the model. The RAND study is a general model for total LCC (3). It attempts to quantify such subjective characteristics as performance, durability, maintainability, and safety over a number of turbine engines (14:7). OS590, on the other hand, avoids this problem by using detailed variables of one specific turbine engine (T 56-7 turbine engine) consisting of delivery schedules, failure rate, labor costs, material costs, and

man-hours per maintenance action (1:B-4). As a result of using such detailed information regarding one engine, it is possible to acquire the data needed for the analysis (2).

Research Objectives

The objectives of this research were to:

1. Analyze the output of OS590 for completeness, sensitivity, validity, and availability of input data;

2. Provide information which will enable the AFAPL to use this model as a tool for LCC analysis for future aircraft turbine engines.

Research Hypothesis

OS590 is a valid model for predicting O&S life cycle costs for aircraft turbine engines.

Research Questions

To accomplish the research objectives, this study was directed toward answering the following research questions:

1. How useful is a sensitivity analysis in validating Logistics Support Cost Model (Program OS590) and identifying cost drivers for engine O&S costs?

2. How could the AFAPL use the Program OS590 as a tool for LCC analysis for future aircraft turbine engines?

CHAPTER II

RESEARCH METHODOLOGY

Overview

The research methodology was designed to analyze OS590 for availability of input data, validity, sensitivity, and completeness. Accurate input data must be available for a life cycle cost model to be useful (7:28). Validity, which is a measure of how well the model represents the real-world environment, was accomplished by verifying the input data to ensure that the computed model output costs are both logical and consistent. Model sensitivity to changes in engine design and other model input parameters was assessed since most life cycle cost models are not sensitive to many engine design and performance parameters associated with Air Force systems and equipment (7:28). Completeness is the determination of which cost elements are appropriate in validating OS590. "The life cycle cost model must include all elements of life cycle cost appropriate to the decision issue under consideration [7:27]."

Population and Assumptions of the Data

The _User's Manual for Life Cycle Cost Models Programs OS602 and OS590_ describes the input data required for OS590

as ". . . a composite of delivery schedules, distributions, failure rates, labor costs, material costs, and man-hours per maintenance action [1:B-5]." Appendix B gives a complete list of the input data and the data sources.

The data population consists of 1,932 T56-7 engines. Within this data population, depot level maintenance, intermediate level maintenance, and mission length data are necessary. Depot level maintenance consists of maintenance man-hours and material costs which were obtained from AFLC. Intermediate level maintenance also consists of maintenance man-hours and material costs which were obtained from MAC owned T56-7 engines. Mission length was obtained from the average MAC C-130 mission. This data represents a census of 1,932 T56-7 engines for the one-year time period extending from October 1977 through September 1978. This data population of T56-7 engines also contains certain necessary assumptions. First, since a majority of the Air Force owned C-130 B/Es are flown and maintained by MAC, the assumption has been made that the intermediate level maintenance man-hours and material costs, as well as the average mission length are representative of the overall T56-7 intermediate maintenance man-hours and material costs, and average C-130 mission length. Secondly, since the T56-7 engine is a mature engine, it was assumed that the engine is in a steady-state condition; therefore, the maintenance

man-hours and material requirements for both intermediate and depot level maintenance will not change. Thirdly, the data obtained from AFR 800-11, AFR 173-10, and T.O. 2J-1-27 was assumed to be complete and accurate.

The following section gives a brief overview of the purpose of OS590 along with a short discussion of its input and output.

Mechanics of the Model

OS590 is a digital computer program designed to forecast maintenance costs and engine requirements based on engine history. The model was designed for multiple engine aircraft with a maximum of four engines (see Appendix A). The input is basically a composite of delivery schedules, the initial engine age distribution, the engine failure distribution, labor costs, material costs, and man-hours per maintenance action. From these data the program estimates the number of man-hours and the cost of maintenance requirements over a pre-specified number of months. This forecast could range from one month to 180 months (fifteen years) depending upon the length of the forecast desired (1:B-4).

Program OS590 Input

To begin the analysis the aircraft, engines, engine inventory, module inventory, engine maintenance, and module maintenance arrays must be initialized. These arrays form

the backbone of the analysis (1:B-19). The program can handle a maximum of 1,000 engines including spares. The computer analyzes which aircraft are grounded, which are active, how many engines are installed, and how many are spares. With this information the computer can calculate the inspection charges incurred during the month. There are six possible inspections to be performed. These are:

1. Calendar - performed once every given number of months
2. Periodic - performed at equal flight hour intervals
3. Phase - specific inspections performed at constant interval hours
4. Daily - performed every day before flying aircraft
5. Pre and/or Post Flight - performed each time the aircraft flies
6. Special Inspection - for unusual maintenance (1:B-22).

After the aircraft inspection charges have been determined, each engine of the aircraft is analyzed for a failure rate calculation using the Weibull failure rate distribution to decide whether an engine will fail or not. The failure rate curve is generated such that the engine represented can fail independent of other engines (1:B-24). If it is determined by the failure rate calculation that a maintenance action is

required, the computer then selects the facility to perform the task. There are six possible maintenance actions related to various maintenance conditions. These actions and conditions are shown in Table 1.

TABLE 1

ENGINE MAINTENANCE ACTION CODE (1:B-26)

Maintenance Action	Maintenance Condition
Attrition	. . . .
Overhaul	Engine time between overhaul (TBO) (3)
Depot major repair	Special inspection (2)
Intermediate major repair	Engine failure (1)
Intermediate minor repair	Non-removable module (0)
Engine removal only	(Used only with 1, 2 or 3 above)

The engine scheduled overhaul (TBO) maintenance action determines if the engine has reached the number of hours requiring a mandatory overhaul, that is, the maximum time between overhauls has been exceeded. Engine special inspection determines if a special inspection is to be performed according to the number of hours on the engine. If the maintenance action is an engine failure, the modules of the engines are then analyzed. These modules, which are particular portions of the engine, also have maintenance actions similar to those used for the basic engine (see Table 1). With the completion of the module analysis, the program is terminated (1:B-28).

Thus far, OS590 has been a maintenance simulation. Resources (aircraft and engines) have been gathered and costs for inspections have been totaled. After completing the inspections, the computer simulates which engines need further maintenance and assigns specific maintenance actions. Finally, the engines which need further work are broken down into their modules to be tested, and required maintenance actions are performed on these modules. In short, Program OS590 input has been a maintenance simulation in tabulating accounts for engine and module repair, labor and material costs, and maintenance tasks and installations over a period of time. This period of time, whether it is five years or fifteen years, is separated into monthly reports which are the outputs of the program. This output is discussed in the next section.

Program OS590 Output

The output for OS590 primarily consists of a forecast which presents the results in an accounting fashion. It covers the manpower and material costs that accompany each type of maintenance action. The maintenance activities listed are inspections, depot overhaul, depot and intermediate major repair, and intermediate minor repair. The module maintenance includes depot overhauls, intermediate repair, and flight-line repair (1:B-16).

Model Analysis

The input, process, and output of OS590 were analyzed to determine if the model meets the requirements of availability of input data, validity, sensitivity, and completeness.

Availability of Input Data

"Accurate input data must be available for a life cycle cost model to be useful [7:28]." As previously stated, the input data come from several Air Force sources which are assumed to be accurate and complete. These input data categories and sources are listed in Appendix B.

If the model has displayed the characteristics of completeness, sensitivity, validity, and availability of input data, then the hypothesis that OS590 is a valid model for predicting O&S costs for aircraft turbine engines is supported. OS590 will also have been shown to be sensitive to certain design parameters and is useful to identify certain engine O&S cost drivers. Finally, since the model is valid and sensitive, it can now be used by the AFAPL for LCC analysis for future aircraft turbine engines. This is so because OS590 contains the flexibility to handle the variable parameters which may occur in future turbine engines. The only limiting factor would be the availability of input data.

Validity

"The validity of a life cycle cost model is a measure of how well the model represents the real-world environment in question [7:28]." First, the input data was verified to ensure that this data is correctly entered into the model (7:28). The verification was accomplished by cross checking the data input cards with the actual data. Second, OS590 was analyzed by a logician from the Directorate of Propulsion, ASD to determine if the model is logically correct. Finally, the output from OS590 must be determined to be logical and consistent. To make this determination the predicted values for engine flight hours, MTBR, Jet Engine Intermediate Maintenance (JEIM) return rate, and fuel consumption (gallons of fuel)[1] for each of the fifteen yearly forecasts were graphically plotted, a trend line was drawn through these forecast points, and a 20 percent confidence band[2] was constructed around this trend line. The reason for the 20 percent confidence band is because any model which predicts life cycle costs involves a certain amount of uncertainty. The 20 percent confidence band around this line is a method of dealing with this uncertainty. That is,

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[1]The OS590 output computes fuel cost rather than fuel consumption. Fuel consumption is computed by dividing fuel cost by the fuel price per gallon.

[2]This confidence band was determined by the AFAPL to be acceptable.

the confidence band gives an interval estimate of the output LCC rather than a point estimate. The next step was to compare the FY78 predictions for fuel consumption, engine flight hours, MTBR, and JEIM return rate with the actual FY78 figures for these categories. These actual FY78 figures must lie within 20 percent of the predicted figures. If the model meets each of the above listed items then the model will be determined to be producing valid O&S costs. It should be emphasized that the results of OS590 are not to be used as a firm O&S cost figure, but rather a figure-of-merit to be used only in cost trade-off studies (8:1).

Sensitivity

The specific design parameters considered in the sensitivity analysis are fuel costs, engine overhaul costs, engine failure rates, and engine TBO. A project engineer from AFAPL stated that these input design parameters are the primary drivers of OS590. He further contended that for OS590 to be considered valid it must be sensitive to the previously mentioned input design parameters (3). The purpose of the sensitivity analysis is to determine if OS590 is sensitive to fuel costs, engine overhaul costs, engine failure rates, and engine TBO. This will be accomplished by varying the aforementioned input design parameters and then determining the effect upon the output values of total material cost, total labor cost, total fuel cost, maintenance

cost per flight hour, and forecast MTBR. If OS590 is not sensitive to these input design parameters, then OS590 will have failed the sensitivity prerequisites in the validation process.

Completeness

A LCC analyst from Aerospace Systems Division stated that OS590 is complete if it contains the following operating and support cost elements which are listed in AFR 800-11, Life Cycle Cost Management Program: intermediate and depot level maintenance manpower and material costs, replenishment spare engines, modifications to the engines, and Petroleum, Oil, and Lubricants (POL) costs. In addition to these costs the model must produce a Mean Time Between Removal (MTBR) rate, total number of engine flight hours, and maintenance cost per engine hour. The output of the model will be analyzed to determine if it contains each of the above elements. The model will be considered complete only if it contains all of the above listed elements (10).

The final step of the research methodology is a list of the assumptions of OS590.

Summary List of OS590 Assumptions

1. OS590 iterates on a monthly basis; therefore, minimum cycle sensitivity will be calculated one month at a time.

2. OS590 assumes packaging costs at 7 percent of maintenance material inspection costs.

3. OS590 will not allow specific work unit code breakdown. It assumes average maintenance cost in terms of man-hours and materials.

4. OS590 does not include base manpower loading. It assumes all maintenance actions are done at one location. However, it does include the maximum number of maintenance actions that can be completed in a month.

5. OS590 assumes all fuel consumption is a result of flying hours.

6. Each engine flies for one month, is inspected, and is then analyzed for failure (1).

CHAPTER III

ANALYSIS AND FINDINGS

Introduction

The methodology for analyzing OS590 was discussed in the previous chapter. The approach taken was to first determine if data for input into OS590 was available; second, to determine if OS590 was producing valid O&S figures; third, to vary several key input parameters to determine if OS590 was sensitive to these parameters; and finally, to examine the output of OS590 to determine if the model was complete. The purpose of this chapter is to state findings that have resulted from the application of the previously stated methodology.

Availability of Input Data

Input data for OS590 was readily available and was gathered by telephone interviews and personal visits. A complete listing of batch card number, category description, input values, and sources are contained in Appendix B.

Validity

Initially, the input data values listed in Appendix B were entered on punched cards. These values were verified to ensure that they were correctly punched on the cards.

The second step in the validation process was to ensure that OS590 was logically correct. This was accomplished by a logician from the Directorate of Propulsion, ASD/YZLR. The logician examined the flow diagram listed in Appendix A and the OS590 program (which may be obtained from the AFAPL) and determined that OS590 was logical and it would properly compute O&S costs (12). The final step in the validation effort was to plot each of the fifteen yearly forecasts for engine flight hours, MTBR, JEIM return rate, and fuel consumption and construct a 20 percent confidence band around the trend line through these forecasts. The actual FY78 values for engine flight hours, MTBR, JEIM return rate, and fuel consumption were then plotted on the appropriate graph. These graphs are located in Appendix C. As can be seen in this appendix, each of the actual FY78 values (▲) lies within the established 20 percent confidence band. The actual engine flight hours for FY78 was 847,719 hours for 1,580 engines, while OS590 computed 438,832 hours for 800 engines. The actual engine flight hours for FY78 based on 1,580 engines was transformed by use of a ratio into the actual engine flight hours based on 800 engines which is the number of engines OS590 used. This equivalent number of actual engine flight hours was 429,225 hours. In comparing actual engine flight hours with predicted engine flight hours from OS590 there was only a 2.2 percent difference. The actual MTBR

for FY78 was 1,567 hours, while OS590 computed an MTBR of 1,545 hours. In comparing actual MTBR for FY78 versus predicted MTBR from OS590, there was only a 1.4 percent difference. The actual JEIM return rate for FY78 was .67, while OS590 calculated a .56 JEIM return rate. In comparing both return rates there was a 19.8 percent difference in actual versus predicted JEIM return rate. The actual fuel consumption for FY78 was 99,539,033 gallons for 199 aircraft, while OS590 predicted 85,045,641 gallons for 200 aircraft. The actual fuel consumption for FY78 based on 199 aircraft was transformed by use of a ratio into the actual fuel consumption figure based on 200 aircraft which is the number of aircraft OS590 used. This equivalent fuel consumption figure was 100,039,230 gallons of fuel. In comparing actual with predicted fuel consumption from OS590 there was a 15 percent difference.

There are several possible reasons for the differences in these forecast values. These differences will be discussed in the final chapter of this thesis.

Sensitivity

A sensitivity analysis was performed on the input parameters of fuel cost, engine failure rate, TBO, and engine overhaul cost, including depot labor rate, depot man-hours, and material cost for overhaul. Twelve simulations were performed. In each simulation, one design

parameter was changed while all other design parameters were held constant at the original input value as listed in Appendix B. Table 2 shows the input parameters, the amount and percentage changed, the output categories, and the amount and percentage that each of these categories changed.

Changes in the input parameters of fuel cost, depot labor rate, depot man-hours for overhaul, and material cost for overhaul resulted in the same amount of change in the associated output categories. For example, a decrease in depot labor rate of 20 percent resulted in a decrease in labor cost at depot overhaul of 20 percent.

A change in either engine TBO or engine failure rate will cause the engine failure curve to change. Since OS590 uses the engine failure curve and a random number generator to derive the number of engines which have failed and thus require repair, then a change in the engine failure curve will cause a change in the number of engines repaired at both the depot and intermediate levels. Table 2 shows that when engine TBO is increased, total number of depot level repairs decreases, the total number of intermediate level repairs increases, and all costs for material, labor, and maintenance decrease. These relationships are logical because as the requirement for time between overhaul (TBO) increases at the depot, the number of depot overhauls will decrease, causing the number of repairs accomplished at the

TABLE 2

SENSITIVITY ANALYSIS

Input Parameter	Original Value	Changed Value	% Change	Output Category	Original Output Value	Changed Output Value	% Change
Fuel cost	$.437	$.85	+94.5%	Total fuel cost	$555,214,974	$1,079,937,593	+94.5%
Fuel cost	$.437	$1.00	+128.8%	Total fuel cost	$555,214,974	$1,270,514,815	+128.8%
Depot labor rate	$25.50	$20.40	-20%	Labor cost at overhaul depot	$ 16,809,039	$ 13,447,231	-20%
				Labor cost at major repair depot	$ 203,873	$ 163,098	-20%
Depot labor rate	$25.50	$30.60	+20%	Labor cost at overhaul depot	$ 16,809,039	$ 20,170,847	+20%
				Labor cost at major repair depot	$ 203,873	$ 244,647	+20%
Depot man-hours for overhaul	313	250.4	-20%	Labor man-hours used at overhaul depot	$ 659,178	$ 527,342	-20%
Depot man-hours for overhaul	313	375.6	+20%	Labor man-hours used at overhaul depot	$ 659,178	$ 791,014	+20%
Material cost for overhaul	$34,105	$27,284	-20%	Material cost for overhaul depot	$ 71,825,130	$ 57,460,104	-20%
Material cost for overhaul	$34,105	$40,926	+20%	Material cost for overhaul depot	$ 71,825,130	$ 86,190,156	+20%
Engine TBO	5,000 hrs.	10,000 hrs.	+100%	Total number of depot level repairs	2,147	1,357	-36.8%
				Total number of intermediate level repairs	2,420	2,893	+19.5%
				Avg. MTBR	1,435	1,542	+7.5%
				Total material cost	$ 78,176,930	$ 50,517,775	-35.4%
				Total labor cost	$ 36,141,128	$ 29,875,700	-17.3%
				Total maintenance cost	$114,318,058	$ 80,393,475	-29.7%

TABLE 2--Continued

Input Parameter	Original Value	Changed Value	% Change	Output Category	Original Output Value	Changed Output Value	% Change
Engine TBO	5,000 hrs.	2,500 hrs.	-100%	Total number of depot level repairs	2,147	3,987	+85.7%
				Total number of intermediate level repairs	2,420	1,538	-36.4%
				Avg. MTBR	1,435	1,177	-18.0%
				Total material cost	$ 78,176,930	$ 141,271,180	+80.7%
				Total labor cost	$ 36,141,128	$ 50,718,881	+40.3%
				Total maintenanoe cost	$114,318,058	$ 191,990,061	+67.9%
Engine failure rate	.64 failures/ 1,000 hrs.	.25 failures/ 1,000 hrs.	-61%	Total number of depot level repairs	2,147	1,572	-26.8%
				Total number of intermediate level repairs	2,420	843	-65.2%
				Avg. MTBR	1,435	2,714	+89.1%
				Total material cost	$ 78,176,930	$ 59,487,390	-23.9%
				Total labor cost	$ 36,141,128	$ 30,329,484	-16.1%
				Total maintenance cost	$114,318,058	$ 89,816,874	-21.4%
Engine failure rate	.64 failures/ 1,000 hrs.	1.0 failures/ 1,000 hrs.	+36%	Total number of depot level repairs	2,147	2,178	+26.6%
				Total number of intermediate level repairs	2,420	4,088	+68.9%
				Avg. MTBR	1,435	963	-32.9%
				Total material cost	$ 78,176,930	$ 96,184,370	+23.0%
				Total labor cost	$ 36,141,128	$ 41,947,484	+16.1%
				Total maintenance cost	$114,318,058	$ 138,131,854	+20.8%

intermediate level (base) to increase. In addition, an increase in TBO will also cause an increase in MTBR since the time requirement to overhaul the engine has been extended. Finally, an increase in TBO will cause the material, labor, and maintenance costs to decrease because there will be more time between overhauls which reduces the number of tasks to be performed and costs incurred (see Table 2). When observing a decrease in TBO, note that the converse of the above relationships is true (see Table 2).

When engine failure rate is decreased the number of depot and intermediate level repairs is decreased, MTBR is increased, and all costs for material, labor, and maintenance are decreased (see Table 2). As the number of engine failures per 1,000 hours decreases, the total number of engine failures will decrease resulting in fewer repairs. Also the time between removals (MTBR) will increase since there are fewer failures. Finally, as a result of a lower failure rate there will be a decrease in the total number of repairs causing a decrease in material, labor, and maintenance costs. Alternately, an increase in failure rate (see Table 2) results in the converse of the above relationships.

OS590 has two methods for generating engine premature removals. Method 1 is the input of actual engine premature removal values derived from historical data. Method 2 is the input of the Weibull distribution failure

curve parameters, α, β, and θ. "The flexibility of this density is one of its desirable characteristics [2:4-23]." α is the location parameter or the time below which failure will not occur. In OS590 α is preset at zero since failure can occur at time zero. β is the Weibull slope or the shape parameter and θ is the characteristic life or the time to failure which locates the distribution along the x axis (9:294).

> The Weibull distribution is receiving wide application as the failure pattern of . . . mechanical devices, and because of its flexibility, it is also being used to describe failure patterns at the unit and equipment levels [2:4-23].

The user has the option of inputting up to three values for β and three values for θ. Thus a "bathtub" failure curve (see Figure 1) may be generated. The period of time T_0 to T_1 is the early failure or Infant Mortality Period. This is the time period when the engine fails due to material or manufacturing defects. The time period T_1 to T_2 represents the Useful Life Period or the normal operating failures. The final time period T_2 to T_3 represents the Wearout Period or the time period when the engine fails due to excessive age of the system (9:27-28). The following values for β and θ were used to determine how sensitive the model would be to these three values in comparison to using only a single value for β and θ.

In an engine's life, the engine Infant Mortality Period (T_1 - T_0) is shorter in comparison to the Useful

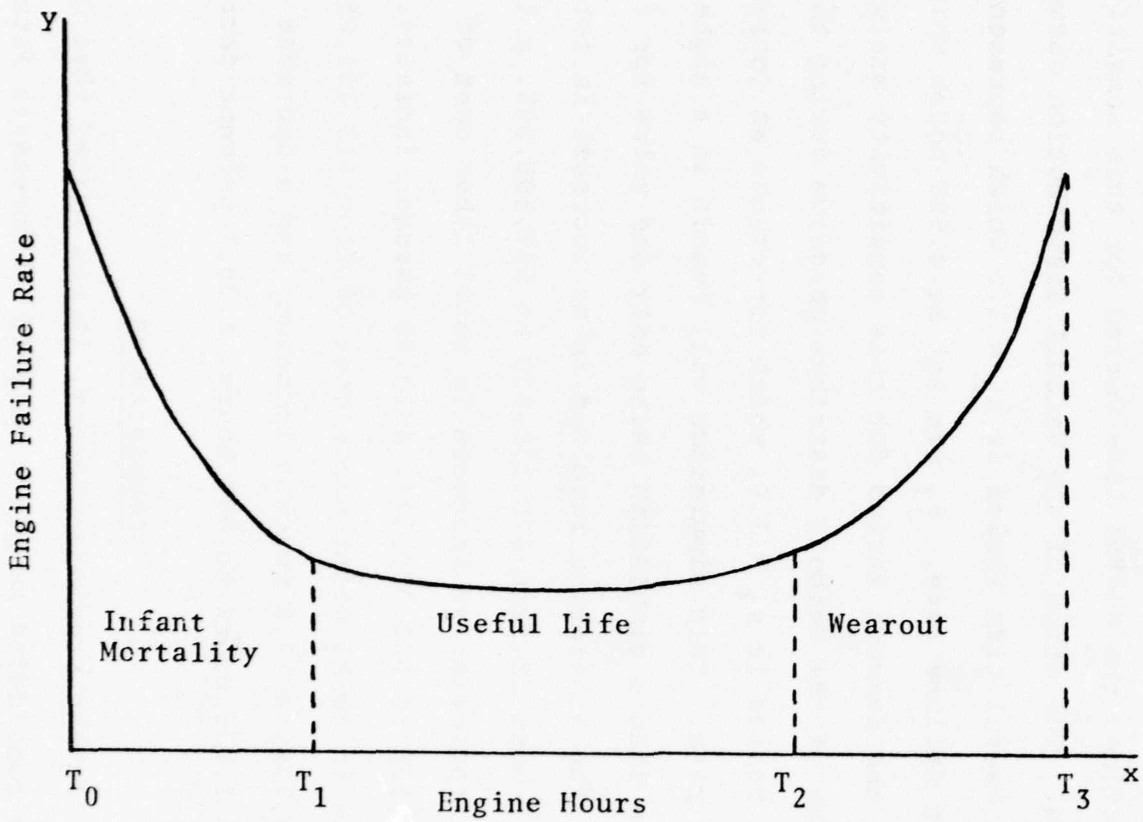


Figure 1. Weibull Failure Distribution Curve

Life Period (T_2 - T_1). θ_1, which is set at 300 hours, defines the Infant Mortality Period for this sensitivity analysis. The slope of the Weibull distribution curve during the Infant Mortality Period is β_1 = .5, which represents a decreasing failure rate. θ_2 was set at 3,000 hours which defines the Useful Life Period for this sensitivity analysis. The slope of the Weibull distribution curve during the Useful Life Period is β_2 = 1.0 which represents a constant failure rate. θ_3 was set at 4,500 hours which defines the Wearout Period for this sensitivity analysis. The slope of the Weibull distribution curve during the Wearout Period is β_3 = 3.0, which represents an increasing failure rate. This simulation will result in a higher failure rate than a simulation using only one value for β and θ.

The simulation resulted in an increase in total material cost of from $78,176,930 to $97,105,205, a 19.5 percent increase; an increase in total labor cost of from $36,141,128 to $42,000,524, a 13.95 percent increase; an increase in total maintenance cost of from $11,431,058 to $13,910,729, a 17.8 percent increase; and a decrease in MTBR of from 1,435 hours to 995 hours, a 30.7 percent decrease.

Completeness

In the previous chapter, it was stated that OS590 will be considered complete only if it forecasts intermediate (or base) and depot level maintenance manpower and

material costs, replenishment spare engines, modifications to the engines, POL costs, MTBR, total number of engine flight hours, and maintenance cost per engine hour. The output of OS590 does produce each of the above categories. Additionally, this was verified by the Plans and Requirements Division, HQ ASD/YZLR (12).

The conclusions and recommendations resulting from this research effort are discussed in the following chapter.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

Overview

This study has been an analysis of Detroit Diesel Allison's operations and support cost model, OS590. This chapter will conclude that OS590 produces valid O&S cost estimates, that the model is sensitive, and that it can be used by the AFAPL as a tool for LCC analysis for future aircraft turbine engines, thus answering the research hypothesis and both research questions. The chapter closes with several recommendations for further research efforts concerning OS590.

Conclusions

As indicated in Chapter I, the objective of this research effort was to analyze the output of OS590 for availability of input data, validity, sensitivity, and completeness.

Accurate input data were available for OS590 as listed in Appendix B. Reliable estimates of important input factors were obtained from various sources within the Air Force and were used to validate OS590. Since input data were available from reliable Air Force sources, the requirement of availability of input data was satisfied.

Validity, which is a measure of how well OS590 represents the real-world environment, was examined as outlined in Chapter III. OS590 represents the real-world environment by simulating a fleet of 200 aircraft with its 936 engines (800 installed plus 136 spares), flies these aircraft, attrites the aircraft and engines, repairs failed engines at all levels of maintenance, and then totals the costs associated with each of these actions. Additionally, the model has the capability to: account for the change in value of money (discount rate), deliver new engines, contain multiple attrition rates, perform engine special inspections, and accomplish each of these functions at the module level with a maximum of eight modules (1:B-13). The input data cards were verified, the model was assessed as logical and consistent by the Directorate of Propulsion, ASD/YZXR, and finally, the FY78 values for engine flight hours, MTBR, JEIM return rate, and fuel consumption were found to be within the 20 percent confidence band around the trend line through the predicted values. Since OS590 met the criteria for validity including the fact that actual FY78 values were within the 20 percent confidence band around OS590 predictions, it can be concluded that OS590 will produce valid O&S costs.

The elements of OS590 which were appropriate in validating its capability for predicting O&S life cycle costs for aircraft turbine engines are also stated in

Chapter III. It can be concluded therefore, that the essentiality of completeness in the validation effort has been satisfied.

In the previous chapter, it was noted that the predicted values of engine flight hours, MTBR, JEIM return rate, and fuel consumption were not the same as the actual FY78 values for these categories. A prime reason for the difference in predicted fuel consumption and actual fuel consumption was that the input value for predicted fuel consumption rate was the AFR 173-10 standard consumption rate of 193.8 gallons per hour. The actual fuel consumption rate, which was calculated by dividing the actual number of gallons of fuel by the actual flying hours, was 233.1 gallons per hour. This rate was higher than the AFR 173-10 rate, which would account for the difference in the OS590 predicted values and actual FY78 values. Additionally, OS590 does not account for the fuel consumed on engine ground runs for maintenance and pre-taxi warm-up. Some of the deviation between the predicted values and the actual values can be explained by the fact that OS590 uses a Monte Carlo simulation to determine whether an engine has failed. The Monte Carlo simulation uses the engine failure curve which can be generated by the model or entered directly by using historical values. In this research effort the model generated the failure curve using a Weibull distribution.

The model generates this distribution by entering two parameters, θ, the characteristic life of the engine, and β, the slope of the curve. As was mentioned in the previous chapter the third Weibull parameter, α, which is the time below which a failure cannot occur, is preset by OS590 at zero. OS590 has the capability for entering three values of θ and β which enables the complete "bathtub" curve to be generated. In the validation portion of this research effort only one value for θ and β was entered. Additionally, the value entered for β was 1.0, which effectively changes this Weibull distribution to an exponential distribution having a constant failure rate. The reason for entering a single value of 1.0 was that actual values for β could not be obtained and it is a convenient practice to assume a constant failure rate (9:229). This is one of the reasons for the difference between the predicted JEIM return rate and actual FY78 value for JEIM return rate. This topic is further discussed in the recommendations section of this chapter.

The sensitivity of OS590 had not been addressed prior to this study; however, OS590 was expected to respond to certain input changes. The changes which were tested for sensitivity consisted of fuel cost, labor rate for depot overhaul, material cost for depot overhaul, characteristic life (θ), and TBO. A direct relationship was found between

the inputs of fuel cost, labor rate for depot overhaul, and material cost for depot overhaul and resulting outputs of total fuel cost, total labor cost, and total material cost. For example, a 20 percent increase in the labor rate for depot overhaul will result in a 20 percent increase in total labor cost (see Table 2). A change in θ or TBO did not have the same direct effect on output as changes in fuel cost, labor rate for depot overhaul, and material cost for depot overhaul. That is, as θ or TBO was increased, the resultant output costs decreased and MTBR increased. When θ or TBO was decreased the resultant costs increased and MTBR decreased (see Table 2). This analysis indicated the direction of change, however, not the amount of change. This is because a change in θ or TBO changed the engine failure distribution curve thus changing the Monte Carlo simulation which in turn changed the output values for total material cost, total labor cost, total maintenance cost, and MTBR. Thus, a question arose as to what amount should be considered as a significant change. The researchers decided, with the concurrence of the AFAPL, that any input change which resulted in an output change of 5 percent or greater would be considered significant (3). As can be seen in Table 2, all of the input changes were at least 20 percent and resulted in output changes, which are considered significant. Therefore, OS590 is determined to be sensitive to the input parameters listed in Table 2.

The additional sensitivity simulation using three Weibull parameters resulted in large, 13.95 percent or greater, changes in the output of OS590. Therefore, it is concluded that OS590 is sensitive to the engine failure distribution curve parameters, and all three parameters should be used when performing cost trade-off analyses.

Research Hypothesis

This study has shown that OS590 has met the established criteria of availability of input data, validity, sensitivity, and completeness, which are necessary characteristics for a useful LCC model. Therefore, the research hypothesis that OS590 is a valid model for predicting O&S life cycle costs for aircraft turbine engines has been satisfied.

Research Question 1

By knowing which input parameters produce significant changes in output, the major cost drivers of OS590 can be determined, which enables OS590 to be used by agencies such as AFAPL in determining the cost drivers on which they should concentrate their research efforts. The first research question listed in Chapter I has been answered.

Research Question 2

Since OS590 has been shown to produce valid O&S cost estimates and is sensitive to fuel cost, labor rate for

depot overhaul, material cost for depot overhaul, characteristic life, TBO, and the "bathtub" failure distribution curve (including three values for θ and β), this model may be further used by the AFAPL as a tool for LCC analyses for future aircraft turbine engines. However, potential users should recognize that the above input parameters are not entirely controllable. That is, fuel cost, labor rate for depot overhaul, and material cost for depot overhaul can be controlled as values input into OS590 but cannot be controlled in the sense that their actual value is determined by economic and other influencing factors. Furthermore, characteristic life, TBO, and the "bathtub" failure distribution curve are cost drivers which are controllable through design changes implemented through the AFAPL. The second research question has been answered.

Recommendations

An immediate possible use for OS590 is for application to the T-56 Engine Model Derivative Program (EMDP) 501-M71 engine. Using OS590, the input data available from the sources listed in Appendix B, and input data on the 501-M71 provided by the contractor, a cost trade-off analysis may be accomplished on the T56 EMDP to determine whether it is more cost effective to purchase this new engine or to keep the T56-7s and T56-15s presently being used by the Air Force.

As indicated in Chapter III, validity of the model was tested through an examination of the model logic and by comparing predicted versus actual values for engine flight hours, fuel consumption, MTBR, and JEIM rate. However, the costs produced by OS590 could not be validated with actual Air Force costs because OS590 was designed to input only one labor cost parameter, direct labor rate, at each level of maintenance. When attempting to find FY78 labor costs a problem was encountered in that labor costs which are reported not only include direct labor costs but also indirect labor costs, supervisory costs, custodial labor costs, and several other miscellaneous costs which are listed in AFLC Regulation 173-10 (16:2-1 to 2-8). It is recommended that a future effort be undertaken to determine how to include these costs into OS590 to make it possible to validate the costs produced by OS590.

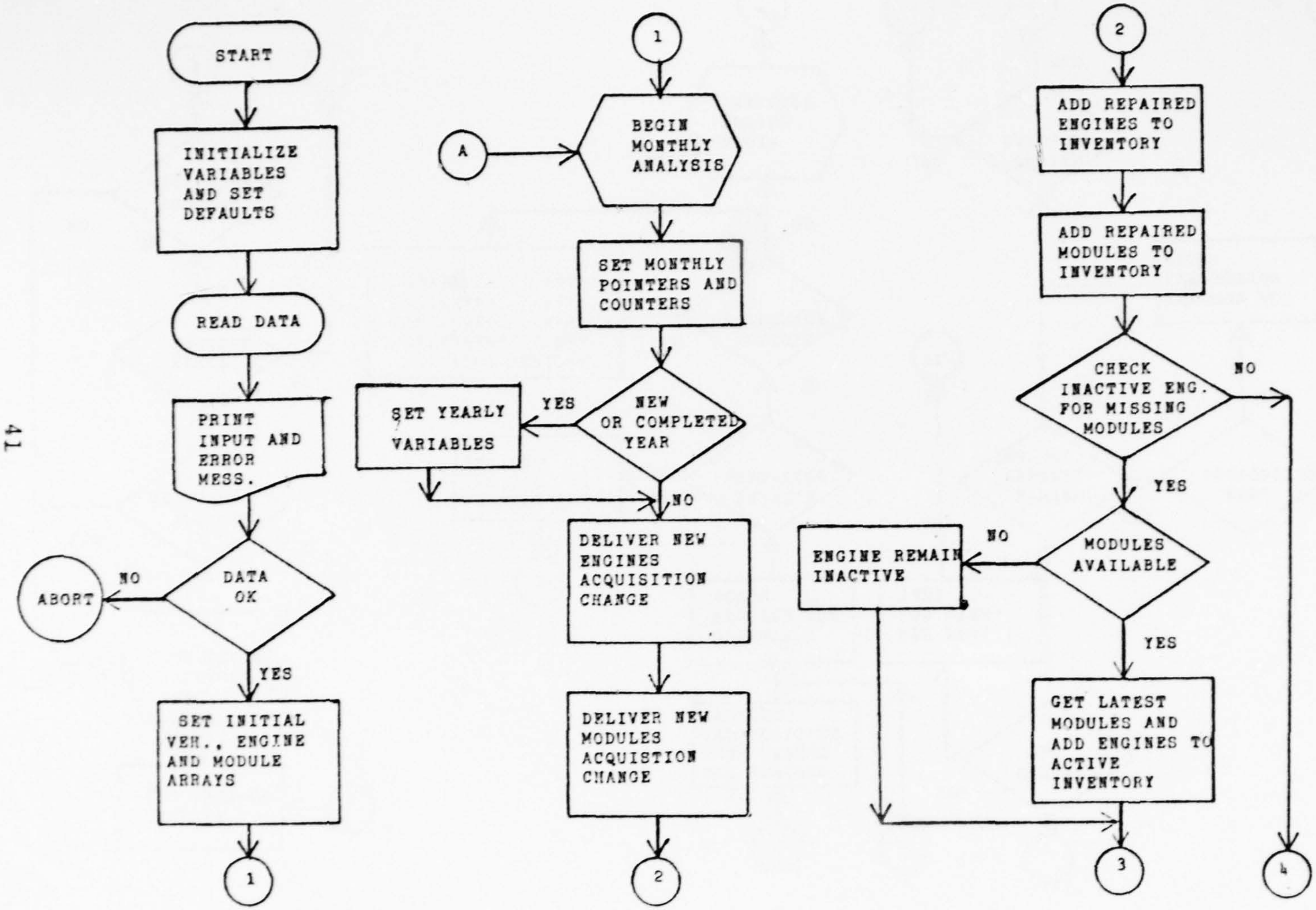
Since the research effort used only FY78 data in the validation effort, future research efforts should be undertaken to obtain actual fiscal year data for several years rather than just one year.

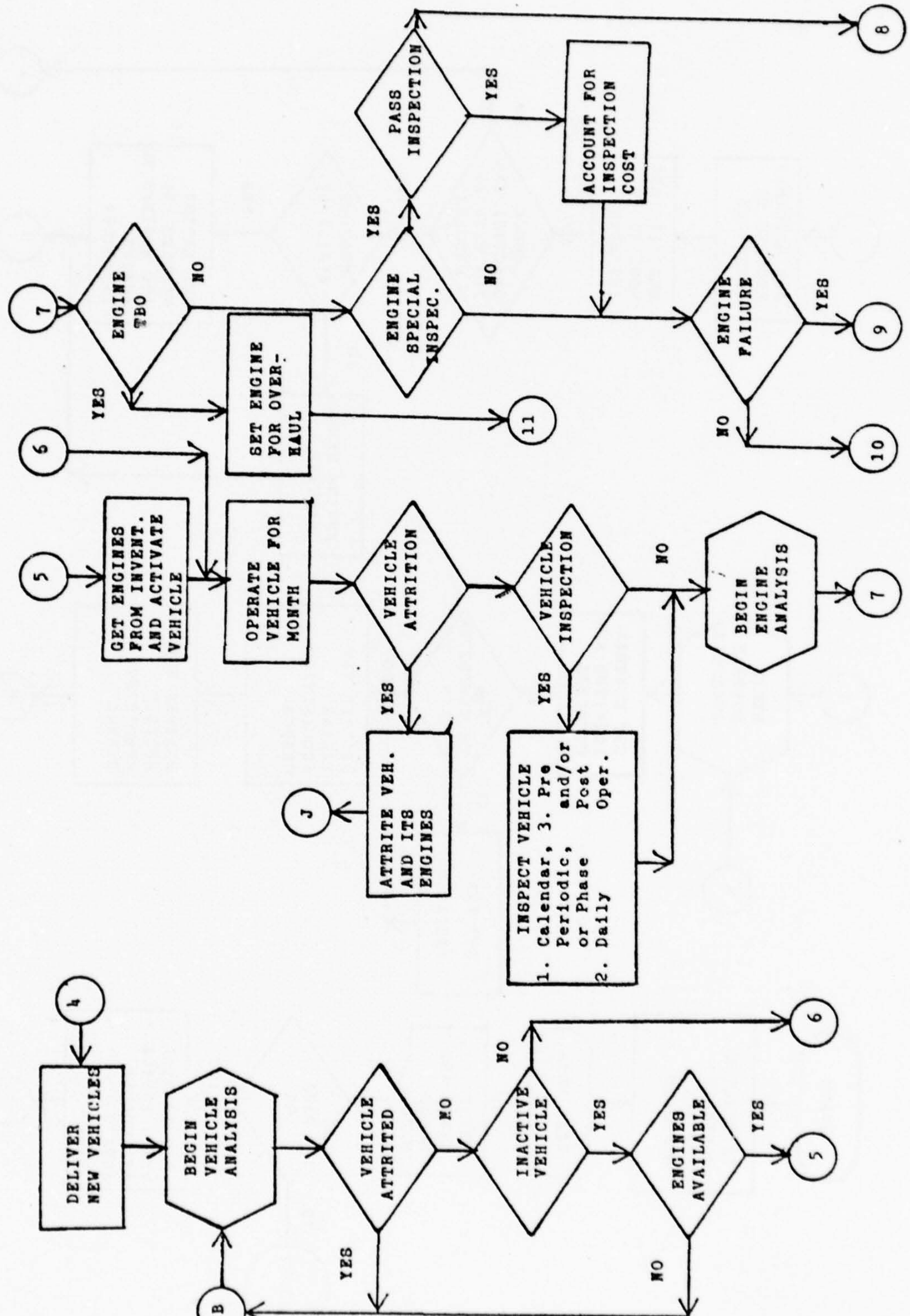
It is also recommended that an attempt be made to determine the actual failure distribution for the T56-7 engine and use this distribution in the model rather than the Weibull distribution. If the actual distribution could be determined, the amounts forecast by the model might more accurately reflect the real-world environment.

APPENDICES

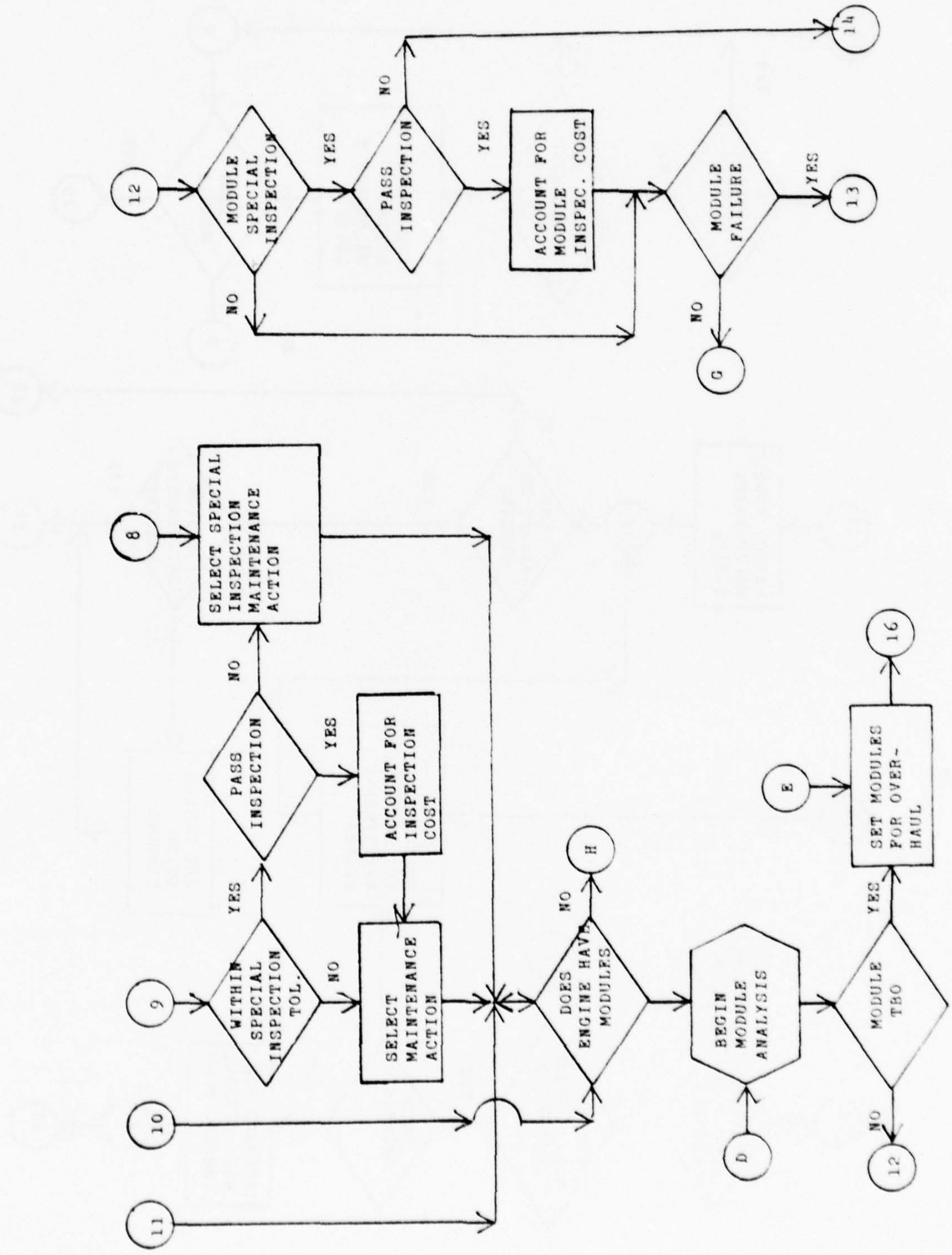
APPENDIX A

OS590 FLOW DIAGRAM

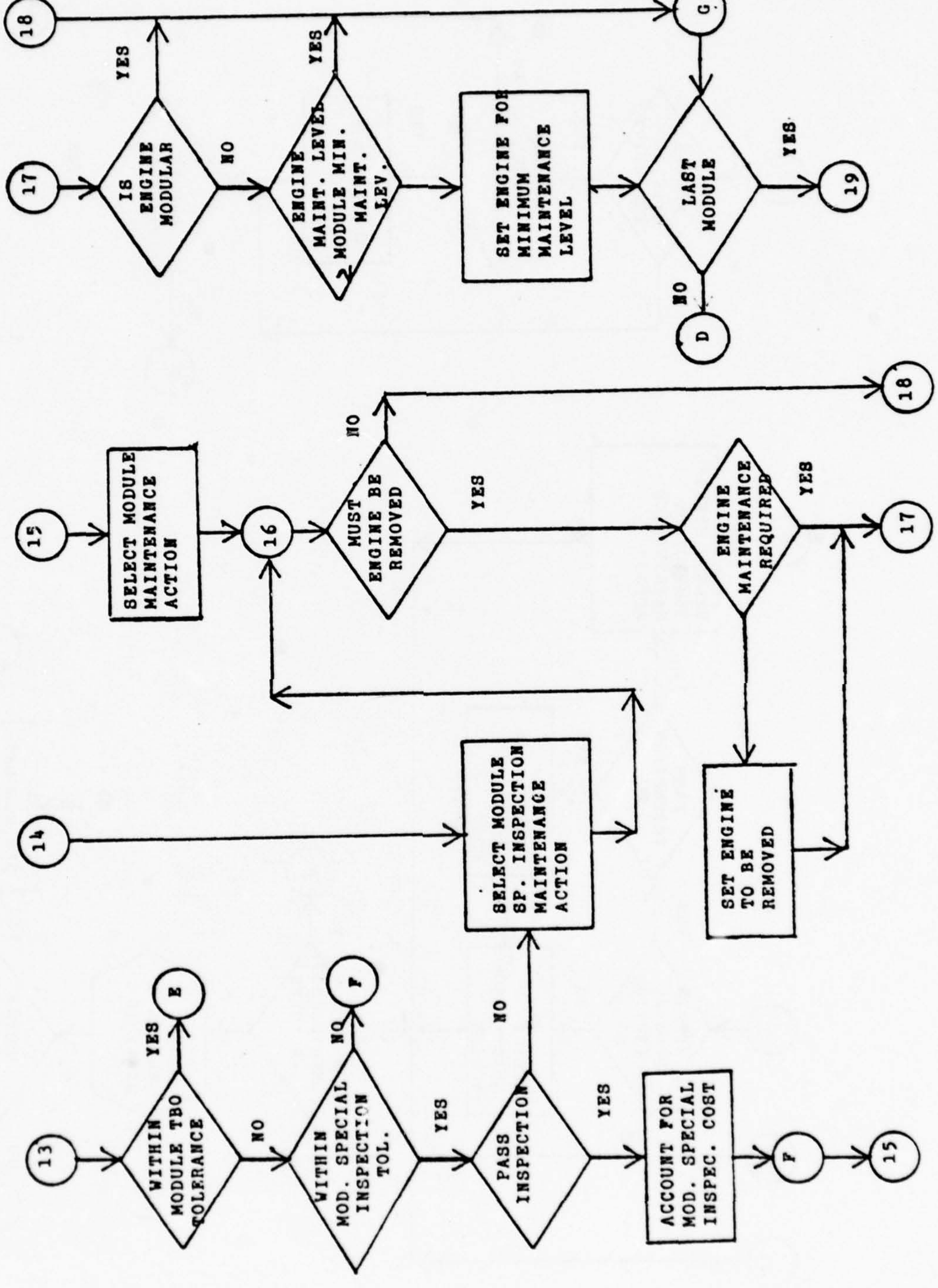

START
INITIALIZE VARIABLES AND SET DEFAULTS
READ DATA
PRINT INPUT AND ERROR MESS.
DATA OK
NO
ABORT
YES
SET INITIAL VEH., ENGINE AND MODULE ARRAYS
1
1
A
BEGIN MONTHLY ANALYSIS
SET MONTHLY POINTERS AND COUNTERS
NEW OR COMPLETED YEAR
YES
SET YEARLY VARIABLES
NO
DELIVER NEW ENGINES ACQUISITION CHANGE
DELIVER NEW MODULES ACQUISTION CHANGE
2
2
ADD REPAIRED ENGINES TO INVENTORY
ADD REPAIRED MODULES TO INVENTORY
CHECK INACTIVE ENG. FOR MISSING MODULES
NO
YES
MODULES AVAILABLE
NO
ENGINE REMAIN INACTIVE
YES
GET LATEST MODULES AND ADD ENGINES TO ACTIVE INVENTORY
3
4



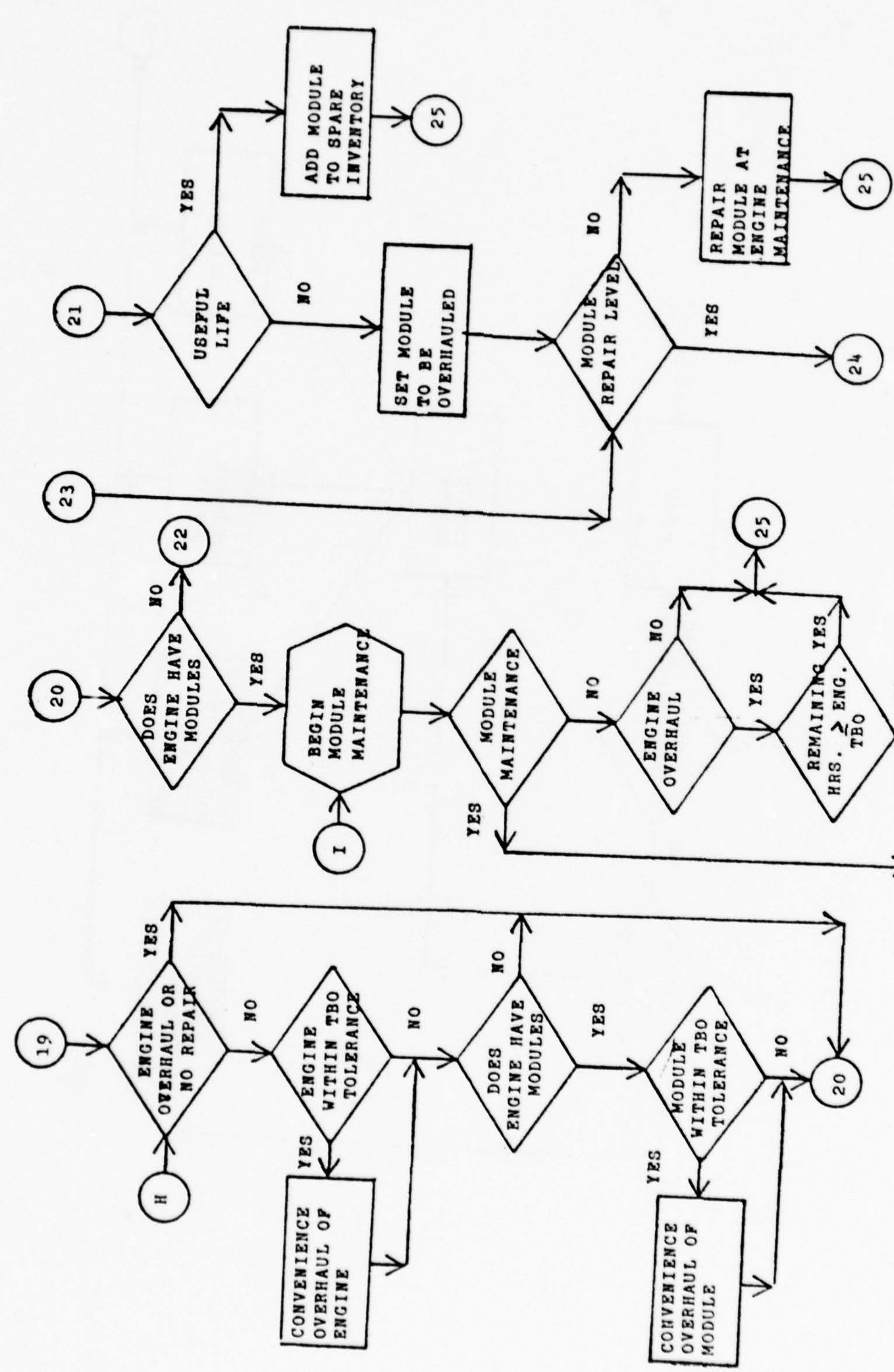
4
DELIVER NEW VEHICLES
BEGIN VEHICLE ANALYSIS
VEHICLE ATTRITED
YES
NO
B
INACTIVE VEHICLE
NO
YES
6
ENGINES AVAILABLE
YES
NO
5
5
GET ENGINES FROM INVENT. AND ACTIVATE VEHICLE
6
OPERATE VEHICLE FOR MONTH
VEHICLE ATTRITION
YES
ATTRITE VEH. AND ITS ENGINES
J
VEHICLE INSPECTION
YES
NO
INSPECT VEHICLE
1. Calendar,
Periodic,
or Phase
2. Daily
3. Pre
and/or
Post
Oper.
BEGIN ENGINE ANALYSIS
7
7
ENGINE TBO
YES
NO
SET ENGINE FOR OVER-HAUL
11
ENGINE SPECIAL INSPEC.
YES
NO
PASS INSPECTION
YES
8
ACCOUNT FOR INSPECTION COST
ENGINE FAILURE
YES
NO
9
10



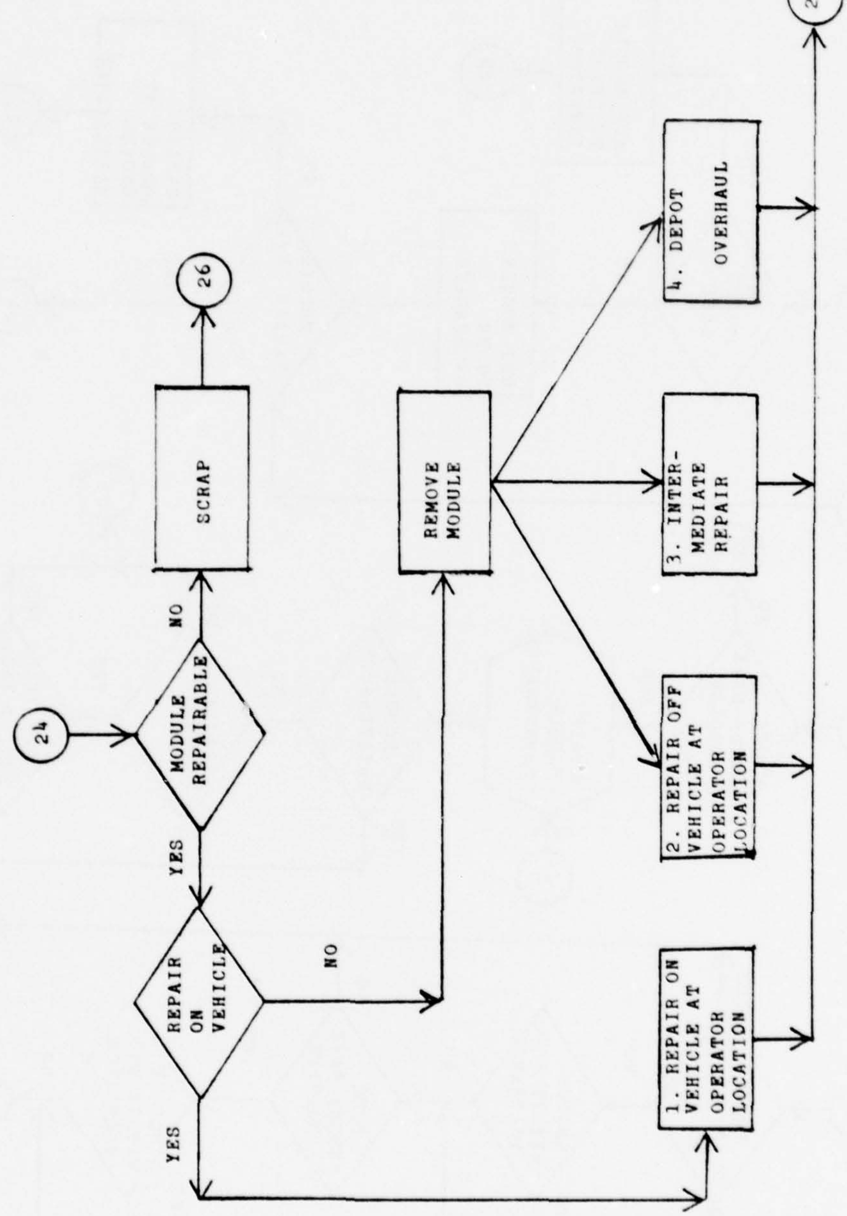
12
MODULE SPECIAL INSPECTION
YES
NO
PASS INSPECTION
YES
NO
14
ACCOUNT FOR MODULE INSPEC. COST
MODULE FAILURE
YES
13
NO
G
8
SELECT SPECIAL INSPECTION MAINTENANCE ACTION
NO
PASS INSPECTION
YES
ACCOUNT FOR INSPECTION COST
9
WITHIN SPECIAL INSPECTION TOL.
YES
NO
SELECT MAINTENANCE ACTION
10
11
DOES ENGINE HAVE MODULES
NO
H
BEGIN MODULE ANALYSIS
D
MODULE TBO
YES
NO
12
E
SET MODULES FOR OVER-HAUL
16



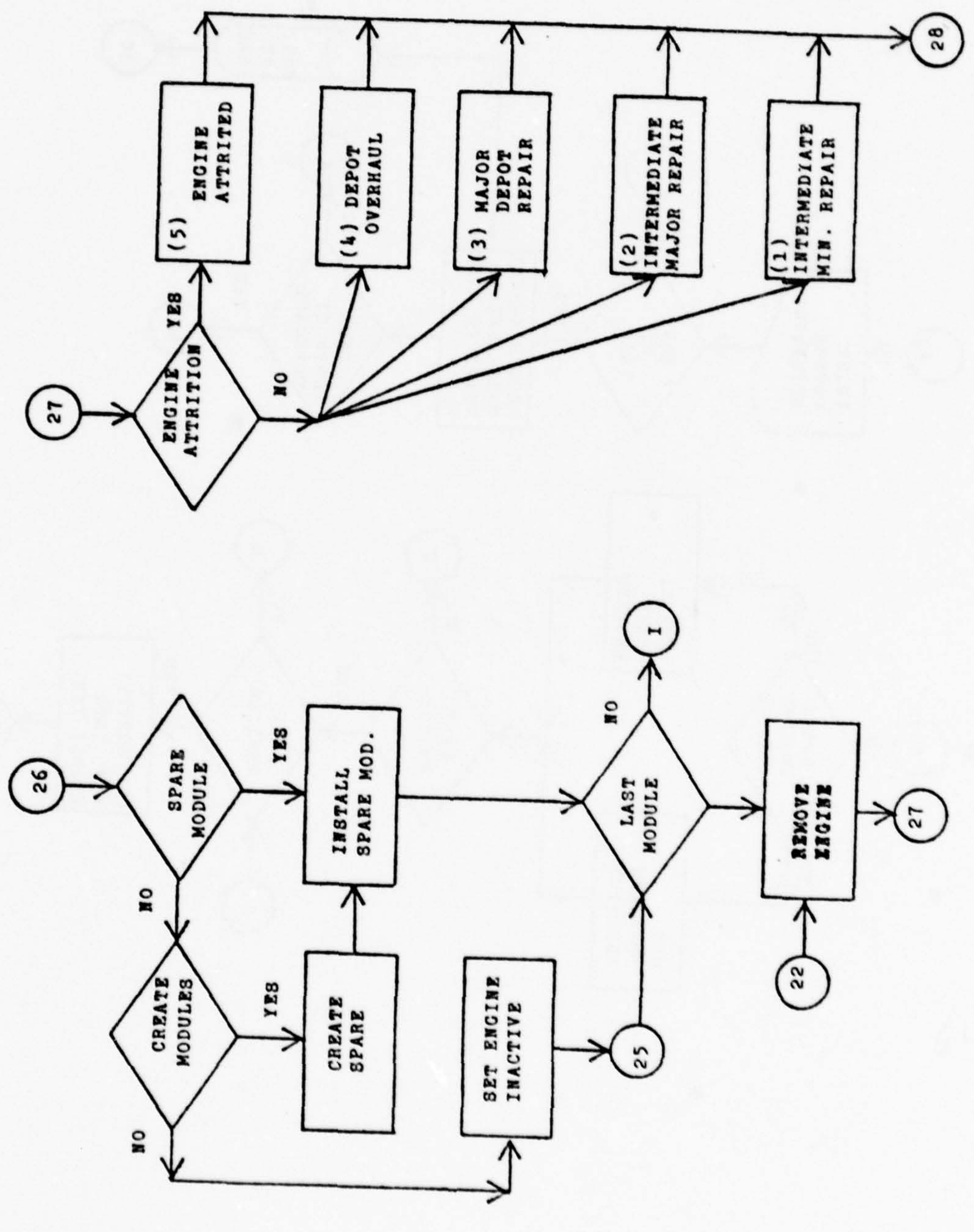
13
WITHIN MODULE TBO TOLERANCE
YES
E
NO
WITHIN MOD. SPECIAL INSPECTION TOL.
NO
F
YES
PASS INSPECTION
NO
YES
ACCOUNT FOR MOD. SPECIAL INSPEC. COST
F
15
14
SELECT MODULE SP. INSPECTION MAINTENANCE ACTION
SET ENGINE TO BE REMOVED
15
SELECT MODULE MAINTENANCE ACTION
16
MUST ENGINE BE REMOVED
NO
18
YES
ENGINE MAINTENANCE REQUIRED
YES
17
17
IS ENGINE MODULAR
YES
18
NO
ENGINE MAINT. LEVEL MODULE MIN. MAINT. LEV.
YES
G
SET ENGINE FOR MINIMUM MAINTENANCE LEVEL
LAST MODULE
YES
19
NO
D



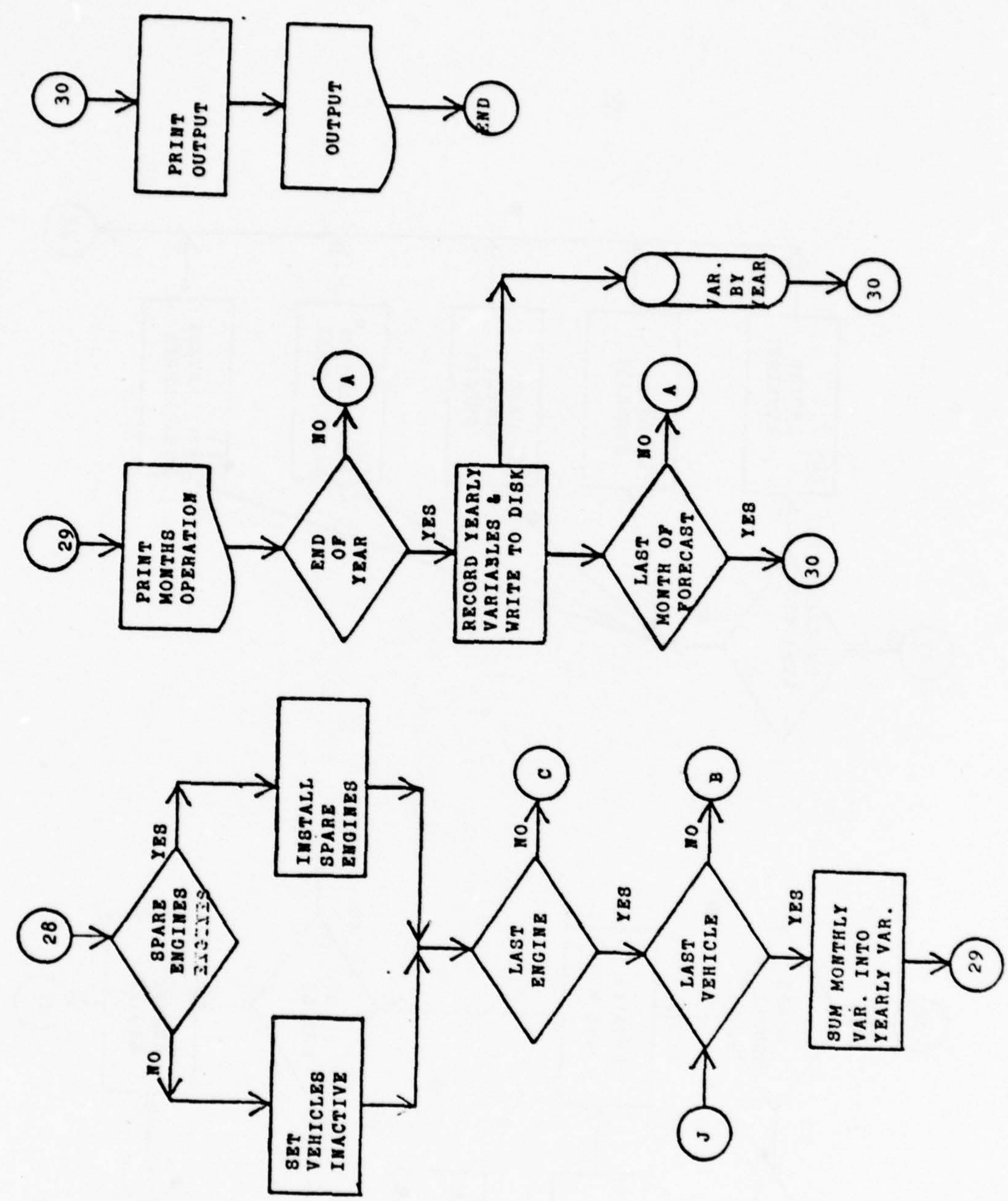
19
H
ENGINE OVERHAUL OR NO REPAIR
YES
NO
ENGINE WITHIN TBO TOLERANCE
YES
CONVENIENCE OVERHAUL OF ENGINE
NO
DOES ENGINE HAVE MODULES
NO
YES
MODULE WITHIN TBO TOLERANCE
YES
CONVENIENCE OVERHAUL OF MODULE
NO
20
20
DOES ENGINE HAVE MODULES
NO
22
YES
BEGIN MODULE MAINTENANCE
I
MODULE MAINTENANCE
YES
23
NO
ENGINE OVERHAUL
NO
YES
REMAINING HRS. ≥ ENG. TBO
YES
25
NO
21
23
21
USEFUL LIFE
YES
ADD MODULE TO SPARE INVENTORY
25
NO
SET MODULE TO BE OVERHAULED
MODULE REPAIR LEVEL
NO
REPAIR MODULE AT ENGINE MAINTENANCE
25
YES
24



24
MODULE REPAIRABLE
NO
SCRAP
26
YES
REPAIR ON VEHICLE
NO
REMOVE MODULE
YES
1. REPAIR ON VEHICLE AT OPERATOR LOCATION
2. REPAIR OFF VEHICLE AT OPERATOR LOCATION
3. INTER- MEDIATE REPAIR
4. DEPOT OVERHAUL
26



26
SPARE MODULE
YES
NO
INSTALL SPARE MOD.
CREATE MODULES
YES
NO
CREATE SPARE
SET ENGINE INACTIVE
25
LAST MODULE
NO
I
REMOVE ENGINE
22
27
27
ENGINE ATTRITION
YES
NO
(5) ENGINE ATTRITED
(4) DEPOT OVERHAUL
(3) MAJOR DEPOT REPAIR
(2) INTERMEDIATE MAJOR REPAIR
(1) INTERMEDIATE MIN. REPAIR
28



28
SPARE ENGINES
YES
NO
INSTALL SPARE ENGINES
SET VEHICLES INACTIVE
LAST ENGINE
NO
C
YES
LAST VEHICLE
NO
B
J
YES
SUM MONTHLY VAR. INTO YEARLY VAR.
29
29
PRINT MONTHS OPERATION
END OF YEAR
NO
A
YES
RECORD YEARLY VARIABLES & WRITE TO DISK
VAR. BY YEAR
30
LAST MONTH OF FORECAST
NO
A
YES
30
30
PRINT OUTPUT
OUTPUT
END

APPENDIX B

OS590 INPUT DATA

Card No.	Description	Value	Source
010	Title cards	N/A	N/A
020	Beginning FY	1978	AFAPL
	Beginning month	1	AFAPL
	Number of months forecast should run	180	AFAPL
	Number of modules per engine	0	AFAPL
	Number of configurations	1	AFAPL
	Number of engines per aircraft	4	AFAPL
	Discounted cash flow factor	0	AFAPL
	Discounted cash flow reference	0	AFAPL
	Labor rate--flight line	$14.42	HQ MAC/LGMWP
	Labor rate--interemediate	$14.42	HQ MAC/LGMWP
	Labor rate--depot	$25.50	SAALC/MMPRR
030	Fuel consumption rate	193.8	HQ USAF/ACB
	Fuel cost per gallon	.437	AFR 173-10
	Average mission length	5.10	HQ MAC/LGMWP
	Can a new aircraft be delivered with a used engine in it?	Y	AFAPL
	Number of days aircraft are used per number	9	AFAPL
040	Not used	N/A	N/A
050	Not used	N/A	N/A
060	Forecast month which attrition rate becomes effective	1	AFAPL
	Attrition rate	.0037	AFR 173-10
070	Number of intervals in distribution	10	AFAPL
	Hours per interval	9.4	AFAPL
	Forecast month distribution becomes effective	1	AFAPL
	Fraction of aircraft which acquire hours within		
	first time interval	.0137	AFLC/LOP-AFAPL
	second time interval	.0628	AFLC/LOP-AFAPL
	third time interval	.1148	AFLC/LOP-AFAPL
	fourth time interval	.1475	AFLC/LOP-AFAPL
	fifth time interval	.1612	AFLC/LOP-AFAPL
	sixth time interval	.1612	AFLC/LOP-AFAPL

Card No.	Description	Value	Source
070	seventh time interval	.1475	AFLC/LOP-AFAPL
(Cont.)	eighth time interval	.1148	AFLC/LOP-AFAPL
	ninth time interval	.0628	AFLC/LOP-AFAPL
	tenth time interval	.0137	AFLC/LOP-AFAPL
080	Number of grounded aircraft at start of forecast with zero engines	0	AFAPL
	Number with one engine	0	AFAPL
	Number with two engines	0	AFAPL
	Number with three engines	0	AFAPL
090	Number of ready to fly aircraft	200	AFAPL
	Number of intervals in distribution	10	AFAPL
	Interval size in hours	500.	AFAPL
	Fraction of engines in		
	interval 1	.1380	AFLC/LOP
	interval 2	.1537	AFLC/LOP
	interval 3	.1353	AFLC/LOP
	interval 4	.1150	AFLC/LOP
	interval 5	.0999	AFLC/LOP
	interval 6	.1071	AFLC/LOP
	interval 7	.1137	AFLC/LOP
	interval 8	.0926	AFLC/LOP
	interval 9	.0388	AFLC/LOP
	interval 10	.0059	AFLC/LOP
100	Number of spare engines	136	T.O. 2J-1-27
	Number of intervals in distribution	7	AFAPL
	Interval size in hours	500.	AFAPL
	Fraction of engines in interval 1	.8294	AFLC/LOP
	interval 2	.0362	AFLC/LOP
	interval 3	.0318	AFLC/LOP
	interval 4	.0271	AFLC/LOP
	interval 5	.0235	AFLC/LOP
	interval 6	.0252	AFLC/LOP
	interval 7	.0268	AFLC/LOP
110	Forecast month which following constraints are to become effective	1	AFAPL
	Maximum number of maintenance actions per month minor repair at intermediate	1,500	AFAPL

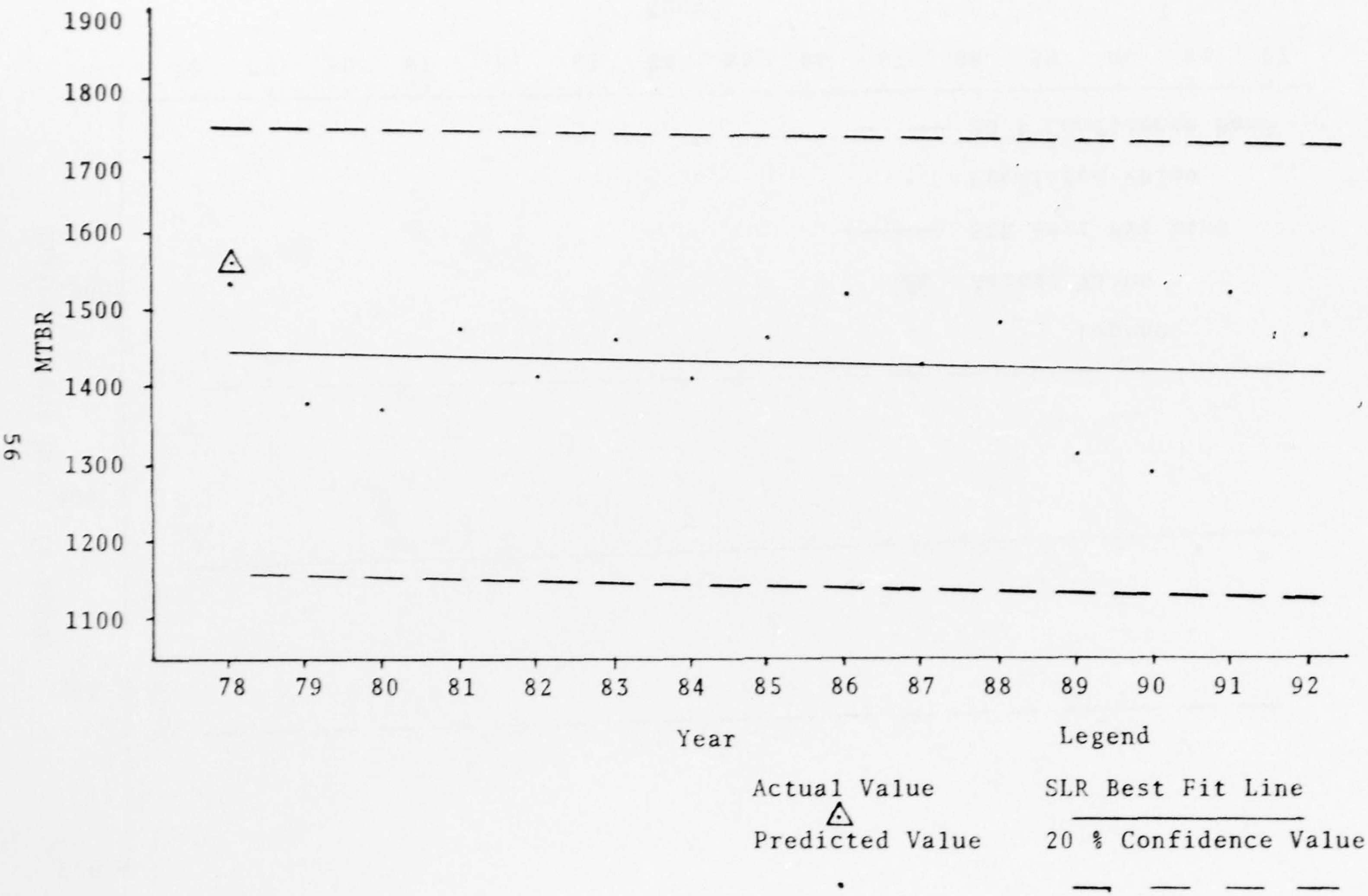
Card No.	Description	Value	Source
110 (Cont.)	Maximum number of maintenance actions per month major repair at intermediate	1,500	AFAPL
	Maximum number of maintenance actions per month major repair at depot	2,000	AFAPL
	Maximum number of maintenance actions per month overhaul at depot	2,000	AFAPL
	Turnaround time in months minor repair intermediate	2	AFAPL
	Turnaround time in months major repair intermediate	2	AFAPL
	Turnaround time in months major repair depot	3	SAALC/MMPRR
	Turnaround time in months overhaul depot	4	SAALC/MMPRR
120	Forecast month the following number of engines will return from overhaul depot	1	AFAPL
	Number of engines returning to spares inventory	12	SAALC/MMPRR
	Month	2	AFAPL
	Number of engines	12	SAALC/MMPRR
130	Forecast month the following number of engines will return from major repair depot	1	AFAPL
	Number of engines returning to spares inventory	1	SAALC/MMPRR
	Month	2	AFAPL
	Number of engines	1	SAALC/MMPRR
140	Forecast month the following number of engines will return from major repair intermediate	1	AFAPL
	Number of engines returning to spares inventory	5	HQ MAC/LGMWP
150	Forecast month the following number of engines will return from minor repair intermediate	1	AFAPL
	Number of engines returning to spares inventory	5	HQ MAC/LGMWP

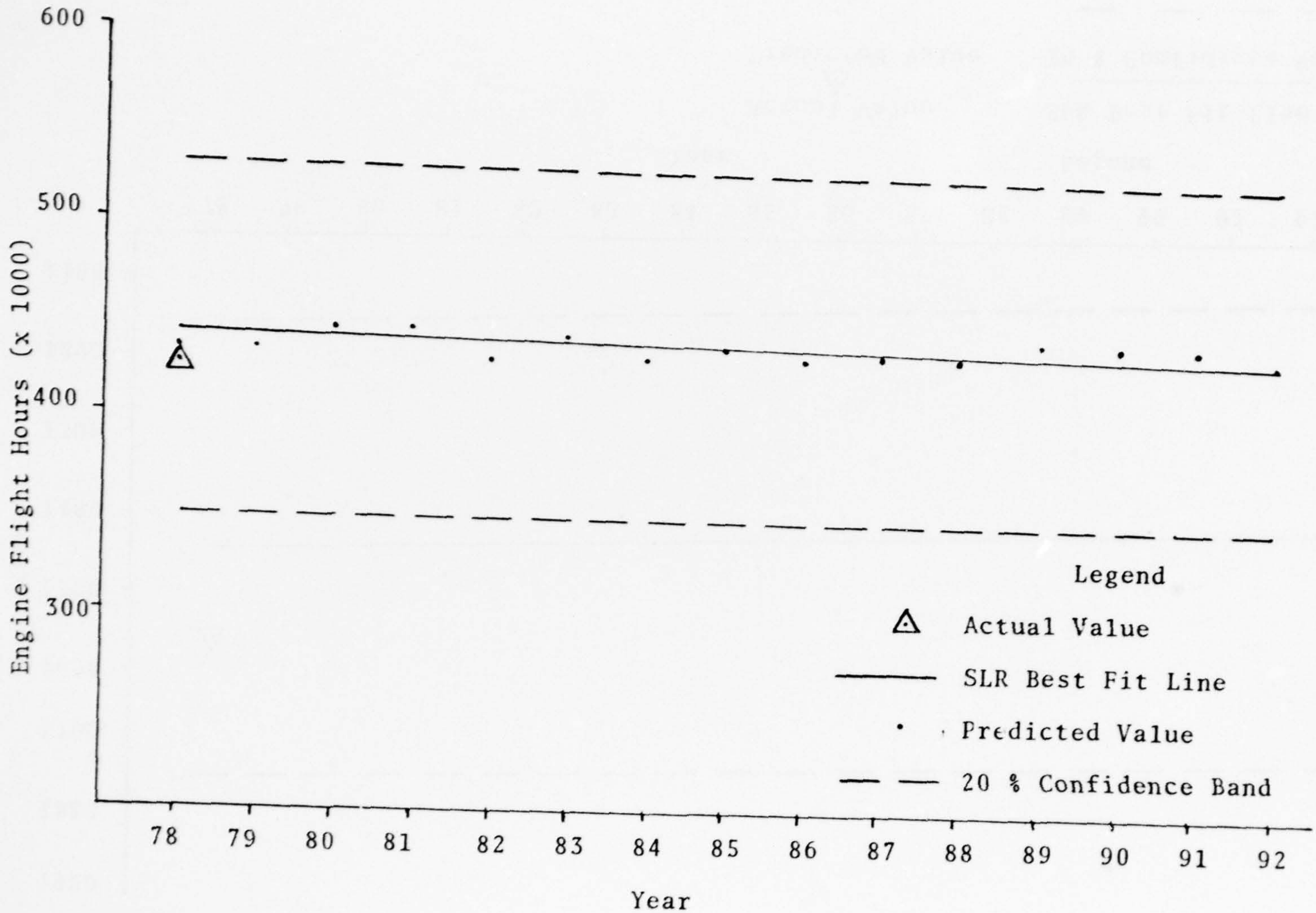
Card No.	Description	Value	Source
160	Overhaul option	1	AFAPL
	TBO tolerance	1,500	T.O. 2J-1-27
	Forecast month TBO becomes effective	1	AFAPL
	TBO in hours	5,000	T.O. 2J-1-27
170	Not used	N/A	N/A
180	Not used	N/A	N/A
190	Not used	N/A	N/A
200	Forecast month	1	AFAPL
	Fraction of removals sent to minor repair intermediate	.4900	AFAPL
	Fraction of removals sent to major repair intermediate	.2100	AFAPL
	Fraction of removals sent to major repair depot	.0150	AFAPL
	Fraction of removals sent to overhaul depot	.2850	AFAPL
	Fraction of removals for attrition	.0	AFAPL
210	Not used	N/A	N/A
220	Not used	N/A	N/A
230	Not used	N/A	N/A
240	Forecast month	1	AFAPL
	Method used to determine premature removals	2	AFAPL
	Characteristic life (θ)	1,562.5	DDA
	Slope (β)	1.0	DDA
250	Not used	N/A	N/A
260	Material cost for calendar inspection	1,300	MAC/LGMWP
	Number of months between calendar inspections	7	T.O. 1C-130A-6
	Man-hour charge for odd number inspections	120.	MAC/LGMWP
	Man-hour charge for even number inspections	120.	MAC/LGMWP

Card No.	Description	Value	Source
270	Not used	N/A	N/A
280	Forecast month	1	AFAPL
	Man-hour charge for preflight inspection	.63	MAC/LGMWP
	Man-hour charge for postflight inspection	1.26	MAC/LGMWP
	Man-hour charge for daily inspection	0.	MAC/LGMWP
290	Forecast month	1	AFAPL
	Man-hour charge for overhaul	313.	SAALC/MMPRR
	Material cost for overhaul	$34,105.	AFLC/MAJA
	Man-hour charge for major repair depot	195.	SAALC/MMPRR
	Material cost for major repair depot	0.0	AFLC/MAJA
	Man-hour charge for major repair intermediate	45.0	MAC/LGMWP
	Material cost for major repair intermediate	0.0	AFLC/MAJA
	Man-hour charge for minor repair intermediate	22.0	MAC/LGMWP
	Material charge for minor repair intermediate	0.0	AFLC/MAJA
	Man-hour charge for engine installation	13.5	MAC/LGMWP
	Material charge for engine installation	0.0	MAC/LGMWP
	Man-hour charge for engine removal	7.5	MAC/LGMWP
300-410	Not used	N/A	N/A
420	End Input	N/A	N/A

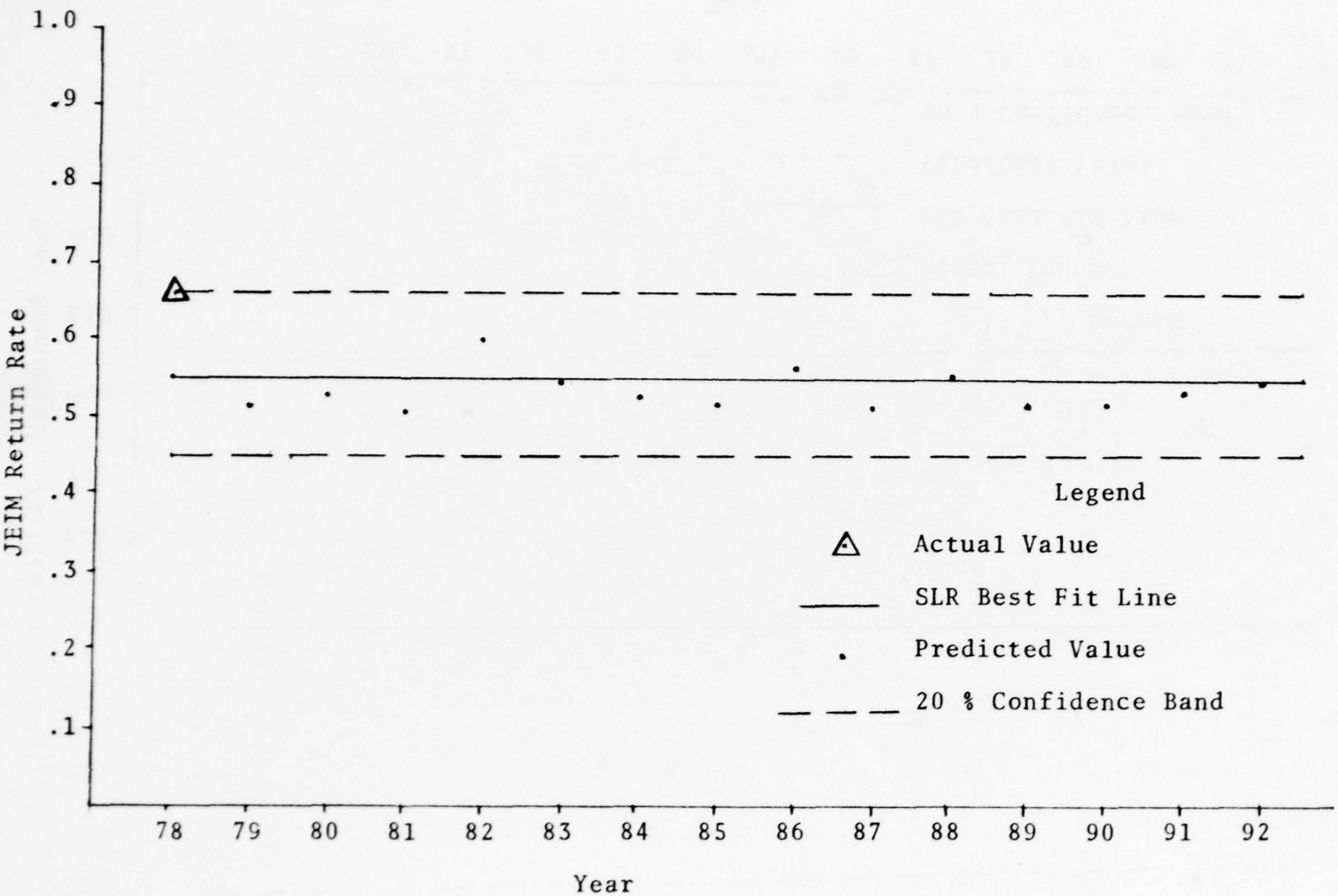
APPENDIX C

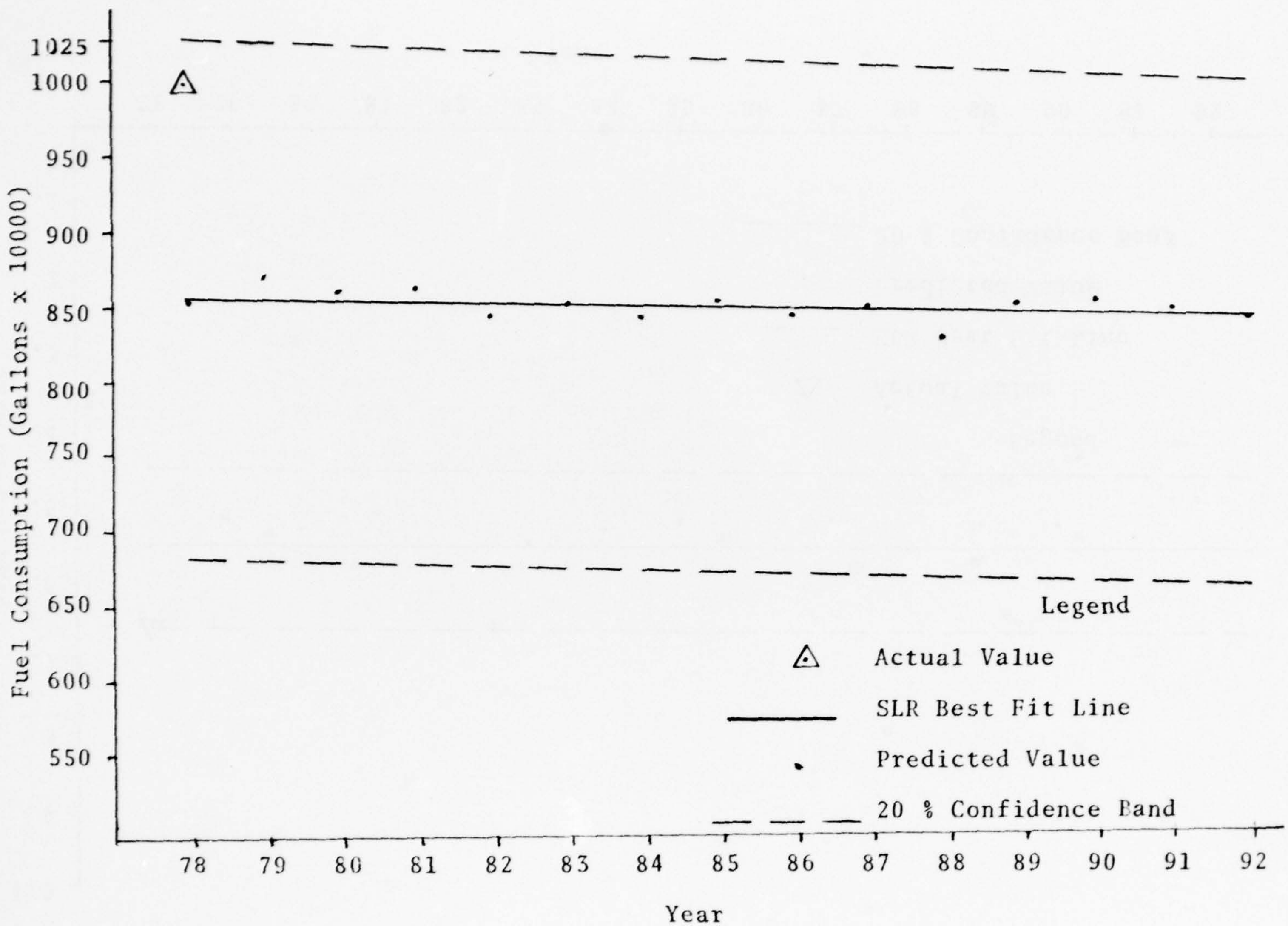
OS590 PREDICTED VALUES


MTBR
1900
1800
1700
1600
1500
1400
1300
1200
1100
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
Year
Legend
Actual Value
Predicted Value
SLR Best Fit Line
20 % Confidence Value



600
500
400
300
Engine Flight Hours (x 1000)
78 79 80 81 82 83 84 85 86 87 88 89 90 91 92
Year
Legend
Actual Value
SLR Best Fit Line
Predicted Value
20 % Confidence Band


JEIM Return Rate
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
Year
Legend
Actual Value
SLR Best Fit Line
Predicted Value
20 % Confidence Band



Fuel Consumption (Gallons x 10000)
1025
1000
950
900
850
800
750
700
650
600
550
78 79 80 81 82 83 84 85 86 87 88 89 90 91 92
Year
Legend
Actual Value
SLR Best Fit Line
Predicted Value
20 % Confidence Band

APPENDIX D

GLOSSARY

The following are definitions of key terms used in this thesis:

Absolute Cost--those all-inclusive costs needed to predict the LCC of a weapon system, subsystem, or component (2).

Aircraft Subsystem--

> Aircraft subsystems include: structures, flight control, avionics, propulsion, hydraulics, electrical, fuel, environmental control, life support, armament, landing gear, instruments, crew escape and support equipment [7:14].

Comparative Cost--those relative costs used for the comparison and selection of one system, subsystem, or component over another system, subsystem or component (3).

Defense System--a major weapon system such as an aircraft or tank (3).

Engine Assembly Level--a number of parts joined together to perform a specific function and capable of disassembly (8:Atch.3).

Engine Level--complete engine (8:Atch.3).

Engine Section Level--the immediate functional breakdown below the engine level (such as fan, compressor, combustor, etc.) which will be defined for each particular program (for modular engines, a section may equate to a module). The total of all sections will equal the whole engine (8:Atch.3).

Life Cycle Cost (LCC) Estimates--estimates of the total cost of a system, subsystem, or component over its full life. They include the cost of development, acquisition, operation, support, and disposal (18:2).

Mature Engine--an engine that has reached a state of full development which is normally from five to eight years old (3).

Source Selection--

> (1) Select contractors who are realistic, credible, and meet Government needs at the right price.
> (2) Assure an unbiased in-depth evaluation of contractor's capabilities in relation to DoD requirements.
> (3) Optimize the Government's operation of the entire selection process [19:2].

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